THE PROFILE MEASUREMENT OF SYNCHROTRON RADIATION MONITOR IN NSRRC

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Abstract

Synchrotron radiation transverse profile measurement system has been operated for ten years. The original system includes optics, image acquisition, image analysis, compressed image transportation and visualization tools at workstation. The existed system suffers with linearity and dynamic problem for some beam physics study. It has been upgraded for various diagnostic and beam physics study recently. The new system is based on a new generation digital camera that is supported to high dynamic range and fast transient image acquisition. The hardware configuration and software structure will be summarized in this report.

INTRODUCTION

Synchrotron radiation monitor measures beam profile and beam size of the synchrotron radiation light source for performance optimization, routine operation check and various beam physics study. The monitor should be able to resolve small transverse beam dimension and motion. This tool is useful for characterizing properties of electron beam analysis since its operation ten years ago. For example, the beam emittance is calculated from the measured beam size.

To improve the functionality of the synchrotron light monitoring system, a major upgrade of the data acquisition and analysis have been done recently. The goal is to increase signal transmission quality, the dynamic range, the linearity of the profile monitor, and better analysis supports. The synchrotron light interferometer (SLI) is also included to measure transverse beam size to eliminate the effect of diffraction, and used as complementary tools. The integration of the system with the control system will be described in the following sections. Some results are also included in the system functional demonstration.

IMAGE ACQUISITION AND DATA ANALYSIS

The synchrotron radiation monitor consists of image forming optics, image capture CCD digital camera and analysis tools. The essential of the optics is necessary to optimize the diffraction effect, depth of field and curvature. FireWire IEEE-1394 CCD camera with 12 bits resolution was chosen to improve the functionality of the image capture and to increase dynamic range (USB2 and Ethernet based scientific CCD camera also emerging market at this moment). The camera embedded ADC on board provides exposure time control and multi-exposures. Windows based-PC running LabVIEW environment is to capture image and to perform pre-processing. This role of front PC also handles some camera parameter control including trigger sources, exposure time, time of multiple exposures …etc. Local display must be supported in the same time. Client applications running on control console can access the CCD camera via LabVIEW server to configure CCD parameters, acquire the image and extract feature parameters from the image. The synchrotron radiation monitor of booster and storage ring, both share the same hardware and software will provide better integration and is easier to maintain.

Functional block diagram of the software environment is shown in figure 1. The control system interface is separated to two layers, is shown in the figure 2.

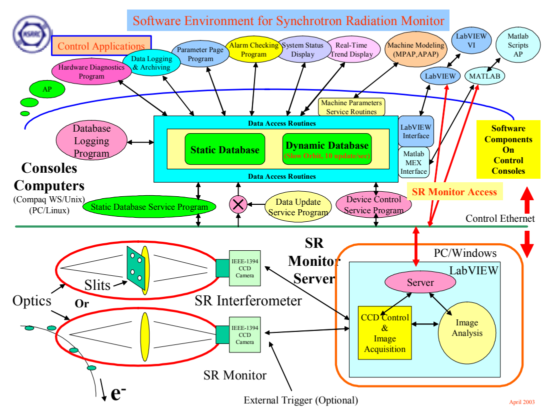

Figure 1: The software system block diagram of the synchrotron radiation monitor.

The local PC is an image server to receive control command from client via TCP/IP protocol. This server is configured to multi-threads software environment. These threads based on LabVIEW include digital camera driver, Ethernet communication, database control code interface node (CIN), data processing by Levenberg-Marquardt method CIN and status display for local/ remote computer. These status include beam size, beam profile display, beam image display, the trigger delay relative to injection timing of booster, and system debug information.

Image analysis includes extracting the orthogonal profile, beam tilt of the profile and interferogram of the SR interferometer. Pattern reorganization syntax approach is to identify beam object. Least square fit are supported to extract beam size and center position. Statistical image analysis tool to analyze spatial moment will be implemented soon to achieve better real-time performance. Application layer is located at workstation/Unix and PC/Linux control console, supporting commercial software Matlab and LabVIEW.

VI pages for routine operation are supported to operate the monitor. The display page also broadcast to the CATV system and access via web. For demand user, Matlab scripts are also supported; the users can configure their measurement by themselves and gain the benefit of powerful image analysis toolbox of the package.

SYNCHROTRON RADIATION MONITOR FOR THE BOOSTER SYNCHROTRON

The synchrotron light monitor for the booster synchrotron is equipping with simple optics. A lens with focal length 500 mm is used to perform 2:1 optics. The band-pass filter is center at 550 nm with 10 nm band pass. The camera is working at external trigger mode. A motorized stage can move the CCD camera to accommodate various operating condition range without readjusting the optics.

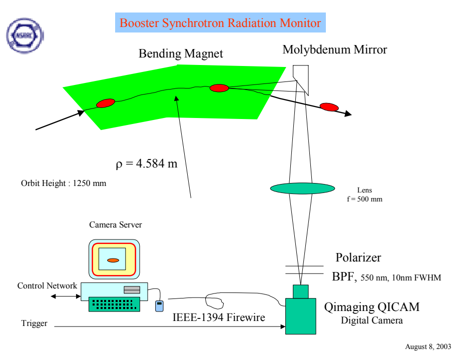

Figure 2: The system block diagram of the booster synchrotron radiation monitor.

Since the booster synchrotron is a 10 Hz machine, the injected beam is accelerated from 50 MeV to 1.5 GeV within 50 ms. The exposure time should be as short as possible. The measurement timing is shown in figure 3. One profile measurement are possible at specific energy by adjusting the delay time. Slipping the delay time, the profile at different energy can be acquired. An example of the measurement is shown in figure 4. The vertical beam size are reduced when energy increase due to strong damping. Multiple exposures will be used for low energy measurement without scarified linearity and dynamics range.

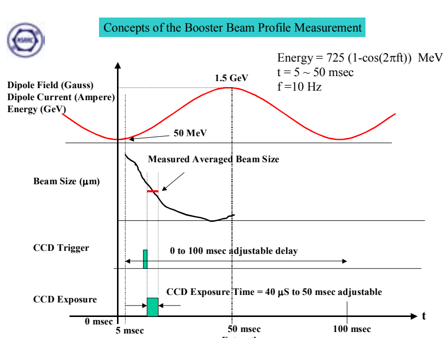

Figure 3: Concept of the measurement sequence during energy ramping of the booster synchrotron.

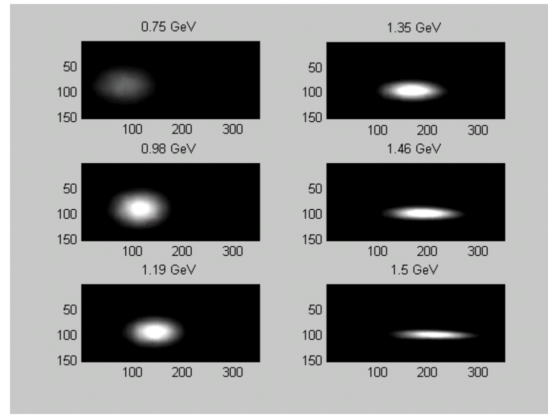

Figure 4: An example of observed beam profile during the ramping with several various energies. One unit in the scale corresponding to 9.4 µm. Exposure time is 0.5 ms.

SYNCHROTRON RADIATION MONITOR FOR THE STORAGE RING

The optics has been optimized to minimized measured error due to diffraction as well as depth of field effects. Narrow band pass filter and neutral density filter are used to reduce chromatic aberration and to extend dynamic range of the CCD camera. The synchrotron radiation monitor system software interface and hardware structure are almost similar to the booster synchrotron radiation. This software interface is also separated to two layers. The system block is shown in the figure 5.

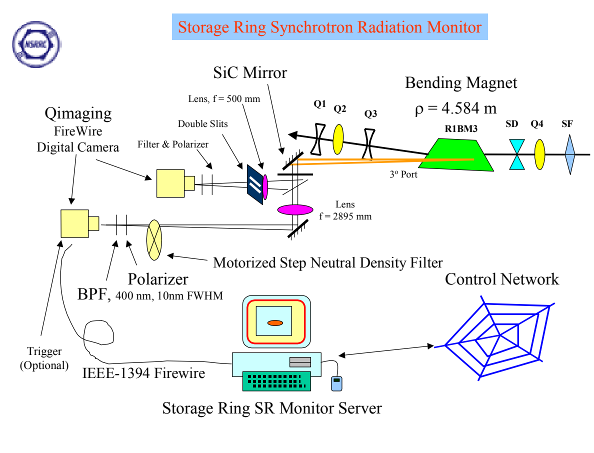

Figure 5: Optics layout of the synchrotron radiation monitor for the storage ring.

Preliminary beam test was done recently. The linearity between electron beam intensity and radiation image intensity in the new system is better than the old system. Accompany with neutral density filter, the dynamic range can be extended to 10^3 and with excellent linearity.

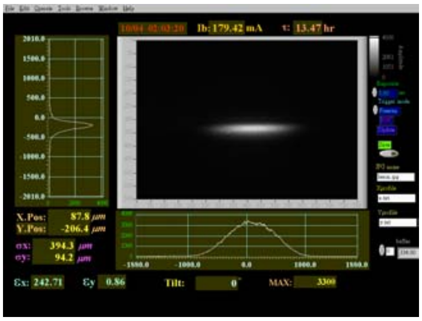

Figure 6: Display page for the storage ring synchrotron radiation monitor.

SYNCHROTRON RADIATION INTERFEROMETER TEST

The synchrotron radiation interferometer realized sub-diffraction-limited beam size in electron storage ring. Successful operation was achieved at several machines [3]. The optics of the existed synchrotron radiation beamline was modified to include SR interferometer. Interferogram of double slits in vertical plane is shown in figure 7. The measured interfeogram is shown in figure 8.

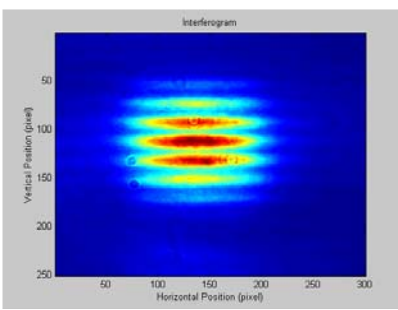

Figure 7: Vertical interferogram of the double slits measurement. (6.7 x 6.7 μm pixel size, 2x2 binning)

The measured interferogram are fitted by the intensity distribution y(x) of the form [3],

$$y(x) = I_o \left[\frac{\sin(\frac{2\pi}{\lambda}\frac{w}{F}x)}{\frac{2\pi}{\lambda}\frac{w}{F}x} \right]^2 (1+\gamma\cos(\frac{2\pi}{\lambda}Dx))$$

where Io is the intensity of the light, y denotes position in the interferogram, D denotes the slit distance, w denotes the half-height of a slit, and F denotes the distance between secondary principle point of the lens and the interferogram. Beam size can be directly related to visibility by following relationship,

$$\sigma_{beam} = \frac{\lambda}{\pi}\frac{F}{D}\sqrt{\frac{1}{2}\ln\left(\frac{1}{\gamma}\right)}$$

The parameter for this test is D=8 mm, w=1 mm, F=2.85 m, λ = 405 nm, the fitted visibility is 0.373, corresponding vertical beam size is 92 um for this test. There are about 10% smaller than the directly imaging profile measurement. Detailed study should be done to find the discrepancy of the results. Two dimensional SR interferometer is also tested. Figure 9 shown the preliminary interferogram. Strong aberration is observed. Further study is needed.

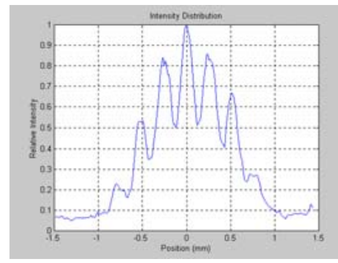

Figure 8: Measured interferogram, the fitted visibility is 0.373.

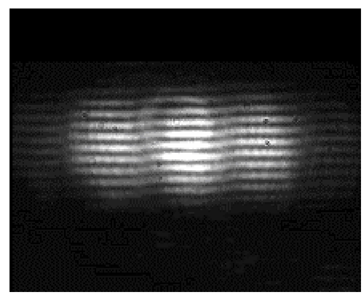

Figure 9: An example for two dimensional interferogram. There are strong aberration due to the imperfect optics.

FUTURE PROSPECTS

Major upgraded items of synchrotron light transverse profile measurement system are scheduled to deploy in the next February. The system enhanced the functionality and performance of the existed system. Synchrotron light interferometer is also implemented to provide micron resolution. Slits with scan mechanism is in implementation. The upgraded synchrotron light monitor system will provide convenient tools for the operation for top-up operation and superconducting RF upgrade of the storage ring soon. Highly linearity will benefits various beam physics measurements.

REFERENCES

[1] C.H. Kuo, et. al., “Transverse Profile Measurement System ay SRRC”, Proceeding of the EPAC’94, 1646 (1994).
[2] Åke Andersson, Juri Tagger, “Beam Profile Measurements at MAX”, NIM A364 (1995) 4-12.
[3] T. Mitsuhashi, “Beam Profile and Size Measurement by SR Interferometers”, in Beam Measurement pp.399-427, edited by S.I. Kurokawa, et. al., World Scientific, 1998.